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# THE IOWA STATE COLLEGE

# Sewage Disposal Plant

AND

# INVESTIGATIONS.

BULLETIN NO. 1.

BY

PROF. ANSON MARSTON
PROF. J. B. WEEMS
PROF. L. H. PAMMEL

Reprint from Proceedings of
IOWA ENGINEERING SOCIETY
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# THE IOWA STATE COLLEGE SEWAGE DISPOSAL PLANT AND INVESTIGATIONS.

By A. Marston.

It is a matter of common knowledge that the subject of sewage disposal is one of great and rapidly growing importance in the old and thickly poulated states of the east, but it is not so commonly realized that this same subject is soon destined also to be of great importance in Iowa. Yet the conditions here are such that in some respects the question is likely to become even more pressing than it is in the east.

Scattered over our fertile prairies are many prosperous villages and small cities, which serve not only as centers of trade, but also as places of residence for the more well-to-do in the surrounding populations. Such towns are coming to require as necessities all the conveniences of modern civilization. The recent past has seen water works systems constructed in nearly every Iowa town of from one thousand to five thousand population, and the installation of electric light plants has had an almost equal development. The author believes that the near future will see a corresponding construction of sewerage systems. When Iowa towns come to look for outlets for such sewerage systems they will not find at hand the numerous perennial streams which have served to carry away the sewage of the great majority of eastern cities. In very many Iowa cases the channels of the only available streams are practically only dry ditches for considerable portions of the average year, and attempts to use them as outlets for sewer systems will result in the creation of open cess pools which will constitute public nuisances requiring abatement by law. Fig. 1 gives a clear illustration of the state of affairs which is likely to confront many an Iowa town in the near future. Evidently methods for sewage purification ought to be planned for from the first in such cases.

When we add to the above facts in connection with our small streams the fact in connection with our large streams that already several Iowa water works are using, as an important portion of their supply, the sewage of cities located above them in the water shed, it becomes apparent that the subject of sewage disposal is one of great importance to citizens of Iowa, especially to her engineers. Hence, no excuse is needed for the presentation to this society of a description

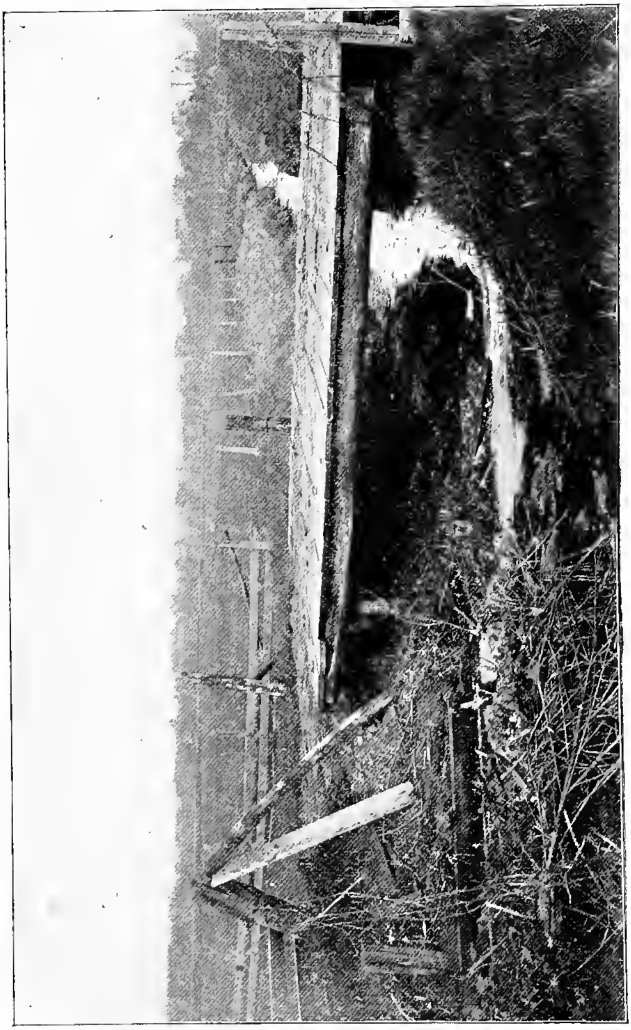


FIG. 1.

of what the author believes is the first sewage disposal plant constructed in the state, the one at the State College at Ames, together with an account of the investigations which have been there undertaken.

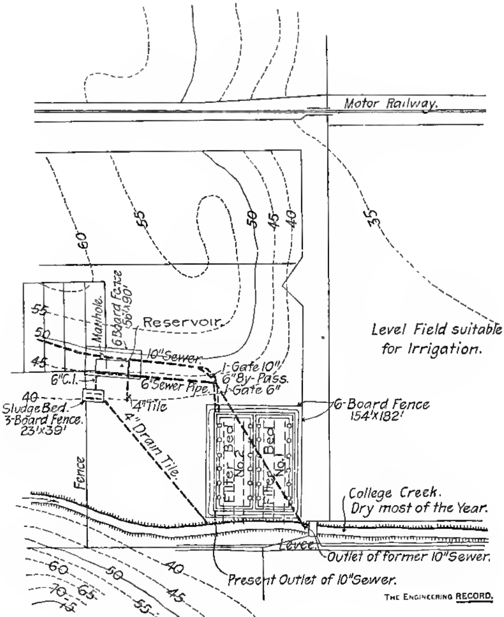
The author believes it to be a fortunate thing that the first sewage disposal plant in Iowa should have chanced to be constructed at a place where it is sure to serve as an object lesson to citizens of the state, and where, by co-operation of various departments of the State College, it has been possible to keep exact records of the plant and to inaugurate sewage disposal investigations. As an object lesson it should help Iowa engineers to prove by actual illustration to town councils the possibility of sewage purification. During the past year the city of Marion, in this state, advertised or bids for the construction of a sewage disposal system. While the author is not very familiar with the circumstances he understands that the city authorities made a trip to Massachusetts in order to see disposal plants actually at work, and that they finally employed an eastern engineer to design their plant. At Ames we hope to help Iowa engineers to prove to other cities that this is unnecessary.

By the investigations which are being conducted at Ames it is hoped, first, to obtain the data needed for the design and operation of sewage disposal plants under Iowa conditions, and, second, to add something if possible to the general stock of knowledge regarding sewage purification.

The sewage disposal plant at the State College was designed by the writer in the winter of 1895-6, and an appropriation for its construction was voted by the Legislature a few months afterward. Delays in construction arose from various causes, so that the plant was not built until 1898. In the final construction the irrigation feature of the original plans was omitted, the money so saved being devoted, as the law permitted, to the extension of the College sewerage system.

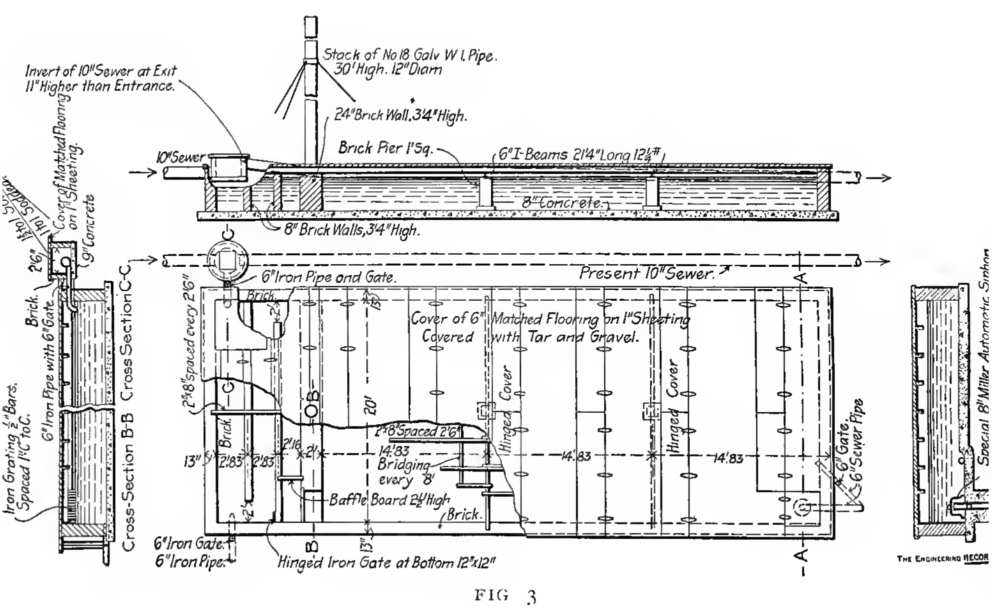
A general plan of the disposal plant as built is shown in Fig. 2. The plant is located about 1,000 feet east of the College Dairy Building, which is the nearest inhabited structure.

The plant consists, first, of a receiving tank, the plans of which are shown in Fig. 3. It will be seen from these plans that this tank is about 22x56x4 feet, having a concrete bottom, brick walls and a wood cover coated with tar and gravel. At the end of the tank where the sewage enters an area about 8x20 feet is partitioned off for a settling chamber, to retain most of the solids in the sewage. By division walls the sewage is compelled to flow slowly back and forth across this chamber for a distance of 60 feet, after which it passes through a screen into the other part of the plant, which is called the flushing



Motor Railway.
60
55
50
45
40
35
Reservoir.
Manhole.
6 Board Fence 50'x90'
10" Sewer.
6" C.I.
6" Sewer Pipe.
1-Gate 10"
6" By-Pass.
1-Gate 6"
4" Tile
4" Drain Tile.
Sludge Bed.
3-Board Fence.
23'x39'
6-Board Fence
154'x182'
Filter Bed No. 2
Filter Bed No. 1
Fence
Level Field suitable
for Irrigation.
College Creek.
Dry most of the Year.
Levee.
Outlet of former 10" Sewer.
Present Outlet of 10" Sewer.
70
65
75
THE ENGINEERING RECORD.


FIG. 2.



Stack of No 18 Galv W I. Pipe.
30' High. 12" Diam
Invert of 10" Sewer at Exit
11" Higher than Entrance.
24" Brick Wall, 3'4" High.
10" Sewer
Brick Pier 1' Sq.
6" I-Beams 21'4" Long 12¼#
8" Concrete.
8" Brick Walls, 3'4" High.
Cover of Matched Flooring on 1" Sheeting.
9" Concrete
Brick.
6" Iron Pipe with 6" Gate.
Iron Grating ½" Bars. Spaced 1" C to C.
Cross-Section B-B
Cross Section C-C
6" Iron Pipe and Gate.
Present 10" Sewer.
Cover of 6" Matched Flooring on 1" Sheeting
Covered with Tar and Gravel.
2"x8" Spaced every 2'6"
2"x8" Spaced 2'6"
Hinged Cover
Hinged Cover
14.83
Bridging every 8'
20'
Baffle Board 2½' High
Brick.
6" Gate.
6" Sewer Pipe
6" Iron Gate.
6" Iron Pipe.
Hinged Iron Gate at Bottom 12"x12"
Special 8" Miller Automatic Siphon
THE ENGINEERING RECORD


FIG 3

chamber. The flushing chamber has a capacity of about 20,000 gallons, and whenever the sewage in it rises to the high water line the entire contents are discharged automatically, by means of an 8-inch Miller automatic siphon, upon the filter beds. By this means an intermittent application of the sewage to the beds is secured.

Detailed plans of the two filter beds are shown in Fig. 4. Each bed is 55 feet by 150 feet, having an area of about two-tenths of an acre, and is made of sand and gravel, 4½ feet deep over the underdrains, and 3½ feet deep midway between them. Mechanical analyses have shown that the average "effective size" of this material is 0.33mm. for Bed No. 1, and 0.37mm. for Bed No. 2. The average "uniformity coefficient" is 10.0 for Bed No. 1, and 7.1 for Bed No. 2. The sewage from the receiving tank is brought in sewer pipes extending along two sides of each bed, and flows out upon the surface through twelve wooden gates for each bed. The effluent is removed by three tile drains under each bed, extending lengthwise of the bed and discharging into the channel of a small brook. These tiles are surrounded by screened and assorted gravel, the finest on top, which extends a few inches in depth over nearly the entire bottom area of the beds. A photographic view of the completed beds is shown in Fig. 5.

About once a month the settling chamber has to be cleaned. This is done readily by opening a valve and allowing the sludge to flow by gravity through a six-inch iron pipe upon the surface of a small, covered sand filter bed, called the sludge bed, located upon lower ground near by. The surface dimensions of the sludge bed are 15x31 feet, its depth of sand and gravel averages 4 feet 3 inches, and it has two tile underdrains. It is covered with a double A roof, made of ship lap in removable panels. A ventilating cupola is also provided. The sludge is allowed to stand on the sludge bed and drain until it becomes dry enough to handle with a shovel, after which it is loaded on a wagon and hauled away to be spread on the College farm for fertilizer. Usually six to eight loads are obtained at each cleaning.

As will be seen by the plans a 10-inch waste sewer is provided, which together with a by-pass, and valves on every pipe line, permits exact control of the disposition of the sewage under all conditions likely to occur.

The cost to the College of the plant as described above was about $2,500, not including engineering, or the printing of specifications and advertising for bids. The contractor lost money on the work, and it is probable that the plant would have cost $2,800 to $3,000 if a fair contractor's profit had been included.

The author desires to acknowledge valuable advice concerning the design of the plant received from Messrs. H. W. Clark and H. F.

Mills, o the Massachusetts State Board of Health. Acknowledgement should also be made of the services of Miss Elmina Wilson, C. E., and of various students of the State College Civil Engineering Department, who assisted in the drafting and in the necessary surveying and inspection.

The sewage disposal plant was put in operation September 15, 1898, and sufficient time has now elapsed to demonstrate that it is an unqualified success. Professors Weems and Pammel will present the details of the chemical and bacterial analyses of the sewage and the purified effluent, which will show that a high degree of purification is effected. The effluent as it issues from the underdrains is as clear, limpid and odorless as the purest spring water. For months at a time the author has kept on his desk a glass vial containing a sample of the effluent, side by side with another vial containing the purest deep well water. Many people examined them, but could not tell them apart, either by appearance or by odor.

Some odor usually exists around the plant, but it is not very strong. and cannot be distinguished at any great distance. At intervals some sediment has to be removed from the surface of the filter beds, and every few weeks their surfaces have to be raked. The beds require careful attention in these particulars, as otherwise they would become clogged at the surface, and the deposits would become offensive. Probably an average of two to three hours' labor per day is required to attend to this and to change the valves and see that everything about the plant is working properly.

Some trouble has been experienced with the working of the Miller automatic siphon, owing to the formation of an oily scum on the surface of the sewage in the flushing chamber which prevents the complete venting of the siphon at the end of the discharge. This leads to a premature discharge next time before the sewage reaches the high water line. A mechanical device to vent the siphon will be tried this year.

In connection with the operation of the plant a continuous automatic record is kept at the rate of flow of the sewage. An inexpensive home-made apparatus is used for this purpose, consisting of a float, a reducing lever, and a cylinder revolved by a common cheap clock. A diagram showing the rates of flow during four weeks in the month of October, 1899, is given in Fig. 6. The rate varies somewhat from month to month, but the average is somewhat more than 40,000 gallons daily. Hence the rate of filtration is over 100,000 gallons per acre per day. As part of the students room away from the college, but are present during a large part of the day time, it is difficult to estimate the exact population which should be counted as contributing to the sewage. Probably 600 persons would be a fair estimate. Con-

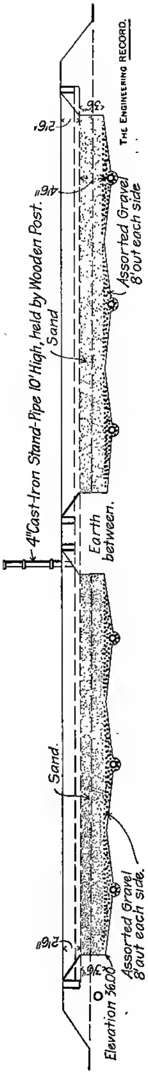



FIG. 4—CROSS SECTION.

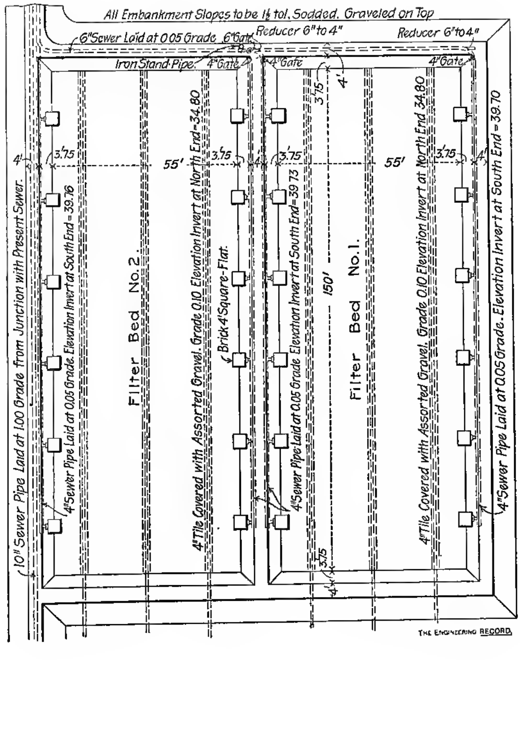



FIG. 4—PLAN.

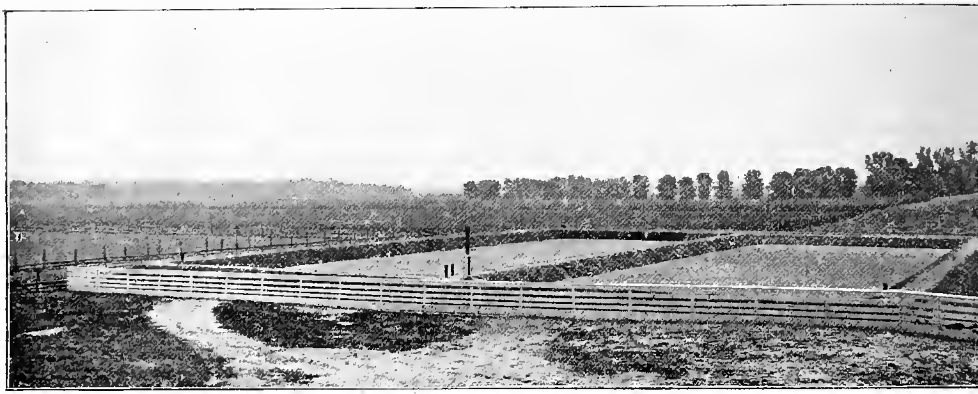


FIG. 5.

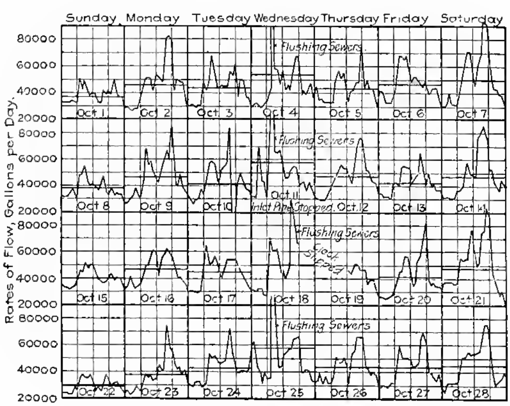

Sunday
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
80000
60000
40000
20000
Rates of Flow, Gallons per Day.
Oct 1
Oct 2
Oct 3
Oct 4
Oct 5
Oct 6
Oct 7
Flushing Sewers
Oct 8
Oct 9
Oct 10
Oct 11
Inlet Pipe Stopped.
Oct. 12
Oct 13
Oct 14
Flushing Sewers
Leak Stopped
Oct 15
Oct 16
Oct 17
Oct 18
Oct 19
Oct 20
Oct 21
Flushing Sewers
Oct 22
Oct 23
Oct 24
Oct 25
Oct 26
Oct 27
Oct 28
The Engineering Record

FIG. 6.

siderable waste also comes from the laboratories and boiler rooms, and several thousands of gallons of sewage per day are contributed by the college creamery. The sewage is usually much stronger than is common. Fig. 6 is interesting as showing the flow of sewage during each hour of the day, and the variations from day to day.

The disposal plant has not yet been operated at full rate during the winter season, owing to the fact that heretofore the long college vacation has occurred in the winter, and during this vacation there is very little sewage floating. During the winter of 1898-9 the sewage was allowed to flow without attention continuously on one bed until, owing to the very severe cold weather and the small volume of sewage, it finally froze up, late in January. This winter more attention has been given the plant, and although the volume of sewage is very small no serious trouble has been experienced. One bed has been furrowed, and the sewage is allowed to flow intermittently on different portions. The long college vacation will hereafter come in the summer time, and next year the plant will be operated with a larger volume of sewage. It is hoped to obtain information as to the operation of such a plant in Iowa winters, which will be of value to Iowa engineers.

In connection with the operation of the plant many temperature records are kept. Since April 26 ,1899, the temperature of the sewage before it enters the receiving tank has ranged from 47 degrees F., October 17th and November 14th, to 78 degrees F., September 5th and September 27th. The temperature of the sewage in the flushing chamber has ranged from 46 degrees F., December 20th and 27th, to 77½ degrees F., September 5th. The temperature of the effluent has ranged from 39 degrees F., January 7th, to 76½ degrees F., August 29th. At the depth of 12 inches in the filter beds the maximum temperature has been 79 degrees F., July 21st; at the depth of 24 inches, 78 degrees F., and at the depth of 36 inches, 76 degrees F., both July 21st. During the present season the frost penetrated at one time over two feet into portions of the beds not in use, and one year ago it froze to the bottom. A complete record of the temperature observations will be published when the investigations have progressed further.

By the cooperation with the author of Professors Weems and Pammel, of the State College, who will themselves discuss their work, regular chemical and bacterial analyses of the sewage before it enters the receiving tank, of the sewage as it flows on the filter beds, and of the effluent have been made. The first object of these investigations has been to develop the conditions and results of the operation of this actual working plant, under Iowa conditions, as this will furnish the data needed for designing and operating plants in this state. When this is accomplished investigations of various special questions relating to sewage disposal will be undertaken. It is o.

course too early to draw conclusions from the work so far done, and what is given here must be considered as merely preliminary. The complete results will be published later by the College. Already, however, the results have considerable bearing upon one of the most important recent developments in sewage disposal, the "Septic tank." The contents of the receiving tank at Ames are removed intermittently instead of continuously as in the English septic tanks, and instead of the air being excluded fresh air is drawn in at each discharge. We are coming now to believe, however, that it is not necessary to exclude the air from the septic tank, and there is no doubt that the Ames tank is greatly beneficial in effecting a partial purification of the sewage, and especially a preliminary breaking up of the organic compounds which leaves them in forms more readily acted on by the purifying organisms of the filter beds. The chemical and bacterial analyses show that the same purification processes go on in the Ames tank as in the English tanks, and to a much greater extent in the shorter time the sewage remains in the tank than one would expect. The sewage at Ames is usually much stronger than ordinary sewage, and a considerable part of the organic matter is removed by settling out as sludge in the settling chamber. Besides this probably some of the organic material escapes from the tank in the gaseous form, and the details of the chemical analyses, as will be explained by Professor Weems, show that the remaining organic material is left in forms much more readily broken up than those in the fresh sewage. In addition, there is usually, though not always, a material reduction in the tank of the bacteria in the sewage.

The benefit resulting from the tank is probably even greater than indicated by the chemical analyses, because the albuminoid ammonia process probably detects a much larger per cent of the partially decomposed organic matter in the tank sewage than it does of the organic matter in the sewage before it enters the tank. On the average the sewage remains in the Ames tank about six to seven hours, as compared with 24 to 36 hours in the ordinary septic tank. Perhaps partly on this account and partly on account of the fact that escape is provided for the gases of decomposition, which in the case of septic sewage have been found injurious to the purifying organisms of the filter beds, we have had no difficulty in establishing nitrification and satisfactory purification in the filter beds, although we work them at the rate of over 100,000 gallons per acre per day, as compared with 60,000 gallons used by the Massachusetts State Board of Health for crude sewage on a filter of similar material. In this connection it should be noted that the Massachusetts filters rest one day in seven, while at the College during 3½ months each year the filters receive only about one-fourth the full amount given.

The author would like to triple the size of the settling chamber of the College plant to see whether the amount of sludge could not be decreased, and the rate of filtration still further increased.

The author would also like to have a couple of "bacteria beds" constructed, so as to compare their efficiency with that of the intermittent filter beds.

A feature of the original plans which was omitted in construction was a pipe line extending east across a level field, with hydrants at short intervals, from which sewage could be drawn for irrigation. It is desired still to add this feature, and then to inaugurate experiments as to the exact value of sewage in irrigating various crops. This work would be done in co-operation with the Iowa Agricultural Experiment Station, which is located at the College. The conditions at the College are more favorable for securing exact data as to the fertilizing value of sewage, and as to the kind of crops best suited to sewage farms, than at any other place known to the writer.

Attention should be called to the fact that the College water supply is taken from a well 2,215 feet deep. The successful operation of the College sewage disposal plant proves that Iowa towns using deep well water can be certain of success in sewage purification. This is likely to be of importance to many places. In examining the results of the chemical analyses, as given by Professor Weems, it should be understood that the "solids" consist mainly of mineral compounds found in the deep well water, and that the effect of these compounds on the "oxygen consumed" is as yet unknown.

In collecting the samples for the bacterial and chemical analyses described by Professors Weems and Pammel the fact that the sewage is collected in the flushing chamber, and discharged only at intervals, was taken advantage of in endeavoring to secure fair average samples of the sewage. In their descriptions the "manhole" sewage is fresh sewage, collected in the manhole just before entering the tank. Samples of this were taken when the flushing chamber was about one-half full, so as to get as fair an average of that particular discharge as possible. In collecting the sample the inflowing sewage was dipped at a rate which gave the desired amount in about five minutes. The "tank" sewage is the sewage as it flows on the filter beds. The samples of tank sewage were collected at intervals during a period of about fifteen minutes at the middle of the discharge. The required amount was taken through a faucet in a small pipe which terminates in the middle line of the discharge pipe near the tank. The samples of effluent were taken at a sufficient length of time after the discharge to come at about the middle of the main effluent flow.

From the methods of collection it will be seen that the samples

of "tank" sewage and effluent are more reliably representative than those of "manhole" sewage. The manhole sewage fluctuates greatly in quality, but the variations must largely disappear in the mixed tank sewage. We have planned a series of analyses to determine the hourly and daily variations in the quality of the sewage, and we caution readers that the reports given in these papers are merely preliminary. For that reason the detailed records are reserved until a greater mass of data has been accumulated. Professor Weems has also planned investigations as to the effect of the mineral matter in the deep well water on the amount of "oxygen consumed." We have also planned investigations to determine the quality and best methods of purification of the creamery sewage by itself.

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## THE CHEMICAL INVESTIGATION OF THE COLLEGE SEWAGE PLANT.

By. J. B. Weems.

In connection with the chemical work in the investigation of the sewage plant of the Iowa State College it may be well to say that the methods used were those recommended in the Massachusetts reports on this subject, in order that a satisfactory comparison might be made if this is desirable at any time. The samples were collected each week and as soon as collected the analytical work was begun upon them. The distance between the plant and laboratory is not very far and so only a few minutes passed be ore the samples were being analyzed. The determinations made were of free ammonia, the so-called albuminoid ammonia, chlorin, solids, nitrites and nitrates, oxygen consumed in fifteen minutes and four hours respectively. The sewage as received from the different parts of the plant is very concentrated and it is also noticed that the sewage varied in the samples received, according to the temperature and rainfall. Samples were received from three sources each week, i. e., the manhole, an arrangement made to receive the sewage before it enters the other parts of the plant. The tank furnished the second sample, and the effluent the third. Before proceeding to the consideration of the results on the sewage it may be well to call attention to the chemical composition of the water from the College well. Most of the deep well waters of the state have large amounts of free ammonia and solids, and with the solids a large amount of chlorin as chlorids is generally present. This condition

would naturally lead us to expect that these substances would be found in excess according to the nature of the water supply.

The sanitary analysis of the College well water is as follows:

**Sanitary Analysis.**

| | Parts per Million. |
|---|---|
| Free Ammonia | 1.2 |
| Albuminoid ammonia | Trace |
| Solids | 1258. |
| Nitrogen as nitrites | Trace |
| Nitrogen as nitrates | Trace |

The mineral constituents present in the same water are as shown in the tables given below:

**Mineral Analysis.**

| | Parts per Million. |
|---|---|
| Silica ($SiO_2$) | 3.000 |
| Alumina ($Al_2O_3$) | 7.000 |
| Ferric Oxid ($Fe_2O_3$) | |
| Lime ($CaO$) | 49.300 |
| Magnesia ($MgO$) | 24.300 |
| Soda ($Na_2O$) | 526.800 |
| Chlorin ($Cl$) | 203.800 |
| Sulfur trioxid ($SO_3$) | 429.700 |
| Carbon dioxid ($CO_2$) | 118.800 |
| Water in combination | 17.600 |
| Total | 1380.000 |
| Less oxygen replaced by chlorin | 46.000 |
| Net total | 1334.300 |

**Probable Combinations.**

| | |
|---|---|
| Silica ($SiO_2$) | 3.000 |
| Alumina ($Al_2O_3$) | 7.000 |
| Ferric oxid ($Fe_2O_3$) | |
| Calcium Bicarbonate ($CaH_2((CO_3)_2)$) | 21.700 |
| Magnesium Bicarbonate ($MgH_2(CO_3)_2$) | 88.200 |
| Sodium sulfate ($Na_2SO_4$) | 763.000 |
| Sodium chlorid ($NaCl$) | |
| Sodium acid Carbonate ($NaHCO_3$) | 40.600 |
| Calcium Carbonate ($CaCo_3$) | 74.500 |
| Total | 1334.300 |

To ilustrate the nature of the results obtained in the chemical investigation of the sewage a number of results are taken and grouped

together, and no attempt is made to give the complete record of the work here.

The results are stated in parts per million.

| DATE 1899. | KIND OF SEWAGE | Chlorin | SOLIDS | | | AMMONIA | | NITROGEN | | OXYGEN CONSUMED IN | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | On Evaporation | After heating to 185° | On Ignition | Free | Albuminoid | as Nitrites | as Nitrates | 15 min | 4 hrs |
| May 10 | Manhole | 88 | 1182 | 1147 | 1040 | 36.7 | 22.8 | 0 | t | 81.6 | 129.6 |
| | Tank | 107 | 1628 | 1510 | 1409 | 12.3 | 14.6 | 0 | t | 78. | 177.6 |
| | Effluent | 112 | 1709 | 1575 | 1554 | 0.20 | 0.22 | 0.16 | 10.0 | 6.4 | 44.8 |
| June 15 | Manhole | 94 | 1569 | 1505 | 1 05 | 55.6 | 20.3 | 0 | 0 | 56.0 | 204.8 |
| | Tank | 70 | 1408 | 1420 | 1265 | 16.8 | 14.1 | 0 | 0 | 38.4 | 210.2 |
| | Effluent | 62 | 1489 | 1460 | 1307 | 0.72 | 0. 6 | 0.2 | 6.0 | 17.6 | 43.2 |
| August 17 | Manhole | 107 | 879 | 776 | 604 | 49.7 | 30.6 | 0 | 0 | 105.6 | 206.4 |
| | Tank | 49 | 1086 | 951 | 794 | 18.4 | 19.9 | 0 | 0 | 83.2 | 192.0 |
| | Effluent | 100 | 1383 | 1302 | 1221 | 0.3 | 0.66 | 0.4 | 10.0 | 9.6 | 62.4 |
| Sept. 19 | Manhole | 67 | 1141 | 1024 | 950 | 56.5 | 22.7 | 1.0 | 0.2 | 136.0 | 307.2 |
| | Tank | 67 | 1260 | 1165 | 1026 | 36.5 | 20.9 | 1.0 | t | 78.4 | 172.8 |
| | Effluent | 104 | 1730 | 1635 | 1606 | 0.9 | 0.62 | 0.12 | 8.0 | 9.6 | 56.0 |
| Oct. 17 | Manhole | 70 | 1421 | 1347 | 1212 | 16.6 | 9.6 | 0.4 | 0 | 16.0 | 145.6 |
| | Tank | 71 | 1545 | 1532 | 1275 | 19.2 | 6.0 | 0 | 0 | 40.0 | 174.4 |
| | Effluent | 75 | 1670 | 1538 | 1385 | 0.94 | 0.96 | 0.1 | 8.0 | 4.8 | 51.2 |
| Nov. 14 | Manhole | 71 | 1867 | 1752 | 1419 | 16.3 | 7.4 | 0.4 | 0 | 35.2 | 251.6 |
| | Tank | 139 | 1562 | 1443 | 1356 | 28.7 | 9.7 | 0 | 0 | 134.4 | 198.4 |
| | Effluent | 90 | 1743 | 1702 | 1441 | 1.08 | 0.58 | 0.4 | 5.0 | 4.8 | 12.8 |

For the examples to illustrate the chemical work I have taken one sample for each month for six months. In making a study of these examples it will be seen that the free and albuminoid ammonia are always high and the amounts present vary between wide limits. The results for the sample from the manhole must be taken as representing the condition o' the fresh sewage of the College during the time it was taken. The tank and effluent, however, will give a much better idea as to the condition of the entire quantity of sewage, while the total quantity of ammonia present in the samples will give one a general idea in making the comparison between the condition of the substances present in the sewage ana which furnished the ammonia.

It has been found that the ammonia in both the free and albuminoid condition has been given from the samples in the manhole, or the fresh sewage, and in many cases it was out of the question to determine the point where the free ammonia ceased to be given off and where the reagents should be added for the determination of the albuminoid ammonia.

For illustrating this condition the amounts of ammonia found in the free and albuminoid state from the sample of June 14, 1899, may be taken. The total quantity of free ammonia for the manhole in this

sample of sewage was 55.6 parts per million, for the tank 16.8 parts and the effluent .72 parts, and these amounts were obtained in tubes as follows:

| Number of Tube. | Manhole. | Tank | Effluent. |
|---|---|---|---|
| 1 | 31.5 | 11. | 3.3 |
| 2 | 7.5 | 3. | .8 |
| 3 | 3. | 1.2 | .2 |
| 4 | 2.2 | .8 | .2 |
| 5 | 1.0 | .5 | .0 |
| 6 | 1.2 | .5 | |
| 7 | 1.0 | .3 | |
| 8 | .7 | .2 | |
| 9 | .7 | .2 | |
| 10 | .8 | .0 | |
| 11 | 1.0 | | |
| 12 | .8 | | |
| 13 | .5 | | |
| 14 | .8 | | |
| 15 | 1.0 | | |
| 16 | 1.2 | | |
| 17 | .8 | | |
| 18 | .8 | | |

In the above example the direct readings of the tubes are given and it is not attempted to show any of the actual results in the sense of including the calculations. It will be noticed that the process for making a determination of the free ammonia in the manhole was stopped on account of the fact that there was no sign of a decrease in the amount, or rather of reaching the point where the tube would contain no ammonia, and this was after distilling eighteen tubes or a total of 900 cubic centimeters of the distillate. It will be noticed that after the reading of the tubes reaches about 1. there was little or no change in the case of the manhole, while in the sample from the tank four or five tubes are sufficient to complete the process after the readings of the tubes reach this point. We have had as a general condition, no trouble in reaching this point in the work on the samples from the tank and the effluent, but with the manhole it has been generally the opposite, and in most cases it has been found that ammonia continued to be given off after reaching the eighteenth or twentieth tube. From this it is readily seen that the material in the tank is much more readily acted upon by the chemical reagents in the process than that in the fresh sewage. Another matter of interest in connection with the comparison of the material in the manhole and tank samples is that of the changes taking place during the heating of the solids. In heating the solid residues from these samples to 185°F it is found that the residue from the manhole has a large amount of carbon or similar material; the residue of the sample from the tank at this temperature is generally nearly white or greyish in appearance. The difference in the manner of giving off the ammonia and the changes which the solids undergo during the heating process show that during the stay

of the sewage in the septic tank there is a change which the material passes through, which renders it more readily acted upon by the chemical reagents and heat, and probably more easily changed by the organisms present in the filter beds.

It appears from the examples given that the College sewage is in a more concentrated form than is usually to be expected and with this condition present the natural question which would present itself would be of the nature of the efficiency of the beds for purifying this material. As regards the presence of free ammonia we find that the effluent has a lower amount than is present in the water from many of the deep wells of the state. Regarding the presence of albuminoid ammonia it will be noticed that in examples presented the amount present on May 10 was .22 parts; June 14, .36 parts; August 17, .66 parts; September 19, .62 parts; October 17, .96 parts, and November 14, .58 parts. Naturally the effluent would be condemned as a potable water on account of high amount of albuminoid ammonia, but the sample of May 10, having .22 parts of albuminoid ammonia would almost pass the requirement placed as a limit by the Iowa State Board of Health, that of .15 parts of albuminoid ammonia for surface waters.

The following results taken from the reports of the Massachusetts State Board of Health may be used for comparing the effluent of the College filter beds with results from other sources.

**Yearly Averages of Mass. Filter No. 6. Parts per Million.**

| Year | Gallons per Acre Daily Six Days per Week | Chlorin | Ammonia | | Nitrogen as | | Oxygen Consumed | Bacteria per Cu. Cent |
|---|---|---|---|---|---|---|---|---|
| | | | Free | Al. | Nitrites | Nitrates | | |
| 1888 .. ........ | 39500 | 47.1 | 0.90 | 0.13 | 0.02 | 7.05 | ....... | 3033 |
| 1889 .. ........ | 41000 | 46.1 | 0.06 | 0.09 | 0.00 | 14.20 | ....... | 520 |
| 1890 .. ........ | 55200 | 54.5 | 0.10 | 0.18 | 0.01 | 12.35 | 1.0 | 7969 |
| 1891 .. ........ | 61200 | 73.0 | 1.73 | 0.30 | 0.03 | 13.36 | 2.6 | 6473 |
| 1892 .. ........ | 46900 | 84.2 | 7.05 | 0.44 | 0.32 | 16.17 | 4.0 | 6913 |
| 1893 .. ........ | 85500 | 73.9 | 4.82 | 0.61 | 1.00 | 21.90 | 4.2 | 11790 |
| 1894 .. ........ | 54300 | 98.0 | 1.78 | 0.47 | 0.98 | 29.80 | 4.3 | 10730 |
| 1895 .. ........ | 57600 | 109.6 | 7.27 | 0.70 | 0.80 | 25.4 | 5.4 | 20884 |
| 1896 .. ........ | 56800 | 104.9 | 6.07 | 0.65 | 1.27 | 27.3 | 5.8 | 21200 |
| 1897 .. ........ | 60500 | 80.9 | 4.09 | 0.58 | 0.38 | 28.2 | 4.1 | 11700 |
| 1898 .. ........ | 65600 | 70.6 | 2.21 | 0.41 | 0.16 | 27.3 | 3.5 | 3472 |

It will be seen that the College results compare very favorably. Filter No. 6 has practically the same kind of filtering material as the College filter beds.

These results as a whole must be regarded as preliminary, and there are many problems to be investigated in order to meet many questions which naturally present themselves. The analysis of the water of the deep well which supplies the College with water is pre-

sented here more as representing to a certain extent the water used for the College in a general way. Quite often, however, water is used from the College spring, which is much lower in solids, chlorin, etc., and this will account for the low amount of solids and chlorin found in the sewage at certain times. In presenting this preliminary report I must acknowledge the work of Mr. J. C. Brown, assistant in the Department, and to whom all of the analytical work has been entrusted.

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## BACTERIOLOGICAL STUDY OF THE AMES SEWAGE PLANT AND SOME IOWA WATER SUPPLIES.

By L. H. Pammel.

The general acceptance of the germ theory of disease by physicians and sanitarians has caused the public to give an increased amount of attention to the subject of the disposal of sewage and the use of pure drinking water. The question is not only one of great importance to the large cities where unusual amounts of water are consumed, but smaller cities and even villages are considering the advisability of establishing adequate plants for the disposal of sewage. In Europe, especially the continental countries, Germany and Switzerland, are far in advance of America in the matter of sewage disposal. The eastern cities are far in advance of our western cities in this matter. Rafter and Baker[1] in an admirable treatise on the subject state "Sewage disposal, in its practical application, is comparatively a new subject in the United States; but the rapid growth of population with its movement into cities and towns, has led to a large number of cases throughout the country in which sewage is discharged into streams, ponds or lakes, which are also the sources of public water supplies." James Fuertes[2] has shown in a very graphic manner that more than 75 per cent of the total population of European cities included in this study are supplied with water of a better quality than that from impounding reservoir supplies, of which New York is typical, while in the United States more than 75 per cent are supplied with water of a poorer quality than that from impounding reservoirs. The death rate from typhoid fever can only be diminished by introducing effective sewage plants and providing the people with pure water.

Many small municipalities in this country have not only established a system of water works, chiefly for fire protection, but they are seriously considering the question of good potable water for domestic purposes and an adequate system to dispose of the sewage. The very successful experiments of the Massachusetts State Board of Health[3] have encouraged the smaller municipalities to use the same

1. Sewage Disposal in the U. S., New York 3, 1894.
2. Water and Public Health, 22-35 (Second Ed).
3. Special Report Mass. Board of Health, 1888-9.

methods successfully operated there for a number of years. In the paper by Professor Marston will be found the details of the plant used at the College.

**Reasons for Bacteriological Examination.**

It is only during the last quarter of a century that any attention has been given to a study of the micro-organism of water. The labors of Pasteur and others set at rest the vague theories of Liebig in regard to fermentation and the part micro-organism played in the changes which were observed. Later an undue amount of stress was laid on the bacteriological examination of waters. One writer, John C. Thresh[1] says: "The presence of dead organic matter may be chemically demonstrated, but inasmuch as the nature of this organic matter, whether poisonous or inocuous, is beyond the power of the analyst to reveal, it is obvious that the results of a mere chemical analysis, may often be worthless or misleading." Percy Frankland[2] says: "Indeed, the detection of specific pathogenic bacteria in drinking water is now known to be almost beyond the range of practical politics, and the search for such bacteria is in general, only carried on in deference to the special request of the layman, the uninitiated, or the hopelessly ignorant, whilst it cannot be repeated often enough that any feeling of security which may be gathered from the unsuccessful search for pathogenic bacteria is wholly illusory, and in highest decree dangerous. By far the most important service which has been rendered by bacteriology in this connection is the means of controlling the efficiency of filtration and other purification processes." Great advancement has been made in a bacteriological study of water and sewage in the last fifteen years. Today the subject is generally worked up from the chemico-biological standpoint. The early attempts at a bacteriological examination were of course very crude. Among the early writers who investigated the question mention may be made of the work of Cohn[3] and Radlkofer[4]. The microscopical method employed by these writers is not without its value, especially when dealing with large microscopic organisms like animals' algae, and fungi. The early methods have been greatly improved upon by Kean[5], Sedgwick[6] Rafter[7], and others. For the very successful determination of these

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1. Water and Water Supplies, 160.
2. Jour. of the Sanitary Institute, 20:392.
3. Beitrage zur. Biologie d. Pflanzen, 1:108.
4. Zeitschr. f. Biologie, 1:60.
5. Science, 1889; Feb. 15
6. Rep. Mass. State Board of Health, 1890:803. Jour. N. Eng. Water Works Association, 1889: Sept.
7. Proc. Rochester Acad. Sci., Pt. 2, 1890.

attention may be called to the papers by Parker[8] The successful early attempts at making microscopical examination of sewage were carried out by Beale[9], who studied the constituents of sewage in the mud of the Thames. In the mud examined he found the several constituents of human faeces, starch granules, fragments of vegetable tissue, etc. Sorby[10], another English writer, made an examination of sewage discharge, giving a quantitative method for determining the amount of impurity. The microscopic methods as applied to water and sewage so far as the bacterial contents are concerned are at best crude and unsatisfactory.

### The Use of Modern Bacteriological Methods.

The subject has been approached from two sides. (1.) The dilution method, which consists in diluting the liquid containing the organism, then dividing the diluted material again, repeating this process as often as may be required to meet the particular case. The tubes of flasks of the last dilution should contain only a single germ. This is a somewhat laborious process. For some kinds of work, especially for a qualitative study of the bacterial contents of certain species, this method must be resorted to. It has been used most successfully in the work of Jorgensen and Hansen in their zymotechemical work and Miquel[1] has employed it for quantitative work in France with good results. Now, however, he employs what he calls the mixed process. This process is not essentially different from that now generally employed. (2.) The method of plate cultures first introduced by Koch marks a distinctive advance in bacteriological work. This method is the one now generally used. In this method, a known quantity of water or sewage is collected in sterilized tubes. A fraction of a cubic centimeter is put in melted agar or gelatine, and this is then poured out on plates. It is then put away to allow the germs to develop. In sewage it is necessary to take a known quantity of the sewage and dilute it with sterilized water. One dilution is usually sufficient. In our work we have uesd the plate method and as a medium agar-agar has generally been employed.

### Bacterial Contents of Drinking Water.

A great many waters have been examined from a bacteriological standpoint. The data which have been obtained are valuable, but they do not give us all the required information of what constitutes a really potable water. There are so many sources due largely as the

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8. Rep. Mass. Sta. Bd. Health, Pt. 1, 1890:581.
9. Jour. Roy. Mic. Soc., 4:1; 1884.
10. Rep. of a Mic. Investigation of Thames Muds. App. C. B. Rep. of Roy. Com. on Met. Sew. Discharge.
1. Ann. de. l Observatoire de Montsouris. 1877-1890.

Franklands[1] say, to the manner of collecting the samples, "which in most cases have been collected irrespective of whether the pump had been in operation or not." According to the Franklands a well sunk in the chalk in Kent, England, had only seven germs per cc. on the day of collection, after standing three days there were 495,000 per cc. Long standing, however, reduces the number very materially as I have shown[2]. In one sample of well water examined after three months and during the interval kept in a refrigerator, the number dropped from 7804 in May to 4000 in August. Some bacteriologists limit the number to 40 or 50 per cc. Some place the limit at 1000. Gruber[3] makes certain qualifications, stating that no definite rule can be laid down. It is more important to consider the quality than quantity. Fecal and putrefactive bacteria should at all times be avoided. Quantitively the contents of the same well are subject to wide variations. Rubner[4] gives the bacterial contents of a certain stagnant well at Marburg as follows: On July 10, he obtained 850 germs per cc. On August 25 the same well had 1620, the highest number recorded for the year. The following results show the variation existing in wells in this country:

| Location of Well. | No. of Bacteria per cc. |
|---|---|
| Well No. 2. LaCrosse, Wis. (Pammel)[5] | 5725 |
| Well N. 4. LaCrosse, Wis. (Pammel) | 7804 |
| Well No. 5. LaCrosse, Wis. (Pammel) | 1345 |
| Well 15 ft. deep. Mass. (Sedgwick & Prescott)[6] | 204-526 |
| Well north of Agrl. Hall 20 ft. I. S. C. (Blanche) | 32600 |
| Well Farm barn I. S. C. (Waterhouse) | 480 |
| Well Veterinary Hospital Barn | 250 |
| Well Ames E. Livery Barn (Elmina Wilson [1350 1565, 1772] average | 1562 |

The well north of Agricultural Hall had large open spaces between cover planks and soon after taking samples became dry. Spring water is usually excellent, especially such as comes from our Iowa drift soils. Too frequently, however, springs are open and during rains receive the surface washings. Local conditions may frequently modify the germ content in various ways.

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1. Micro-Organisms in Water, 102.
2. Proc. Ia. Acad. Sci. Pt. 4. 1:94.
3. Die Bacteriologische Wasserruntersnchung u. ihre Ergebuisse.
4. Beitrage zur Lehre von den Wasserbacterien Archiv. f. Hygiene 11:365.
5. Proc. Ia. Acad. Sci. Pt. 4. 1:94.
6. Rep. Mass. Sta. Brd. Health, 26:437.

| Source of Supply. | No. of Bacteria per cc |
|---|---|
| I. S .C. College Spring, Iowa (Pammel)[1] | 56 |
| I. S. C. College Spring from creamery hydrant (Pammel)[1] | 320 |
| Open Spring No. 1 Mass. Edge of meadow (Sedgwick & Pres.)[2] Grown in Gelatin. | 252-258 |
| Open Spring No. 3. Mass. base of meadow of woods and hills( S. & P.)[2] | 92-105 |
| Spring Upper Greens and near Reigate, Eng. (Franklands)[3] | 8 |
| Spring in Zurich. Switzerlaid. (Cramer)[4] | 9-3425 |

## Deep Wells.

The micro organisms of deep wells of this state have not been generally investigated. So far as they have been studied the water contains a small number of germs and none are pathogenic. From the nature of the case these wells should furnish water reasonably free of bacteria. The following table shows the result of our investigations and those of others:

| Location of Well. | No. of Bacteria per cc. |
|---|---|
| Deep well 116 ft. Berlin, Wis. (Russell)[5] | 30 |
| Deep well 2215 f. Ames. (Pammel)[6] | 50 |
| Deep well 2215 ft. Ames. (Fay) | 50 |
| Deep well 2215 ft. Ames (Smith) | 25 |
| Deep well tubular 193 ft., Cambridge, Mass. (S. & P.)[7] | 254-269 |
| Deep well tubular 213 ft., Boston, Mass. (S. & P.) | 130-140 |
| Deep well tubular 750 ft., Roxbury, Mass. (S. & P.) | 38 |
| Deep well tubular, Bath, Eng., Kent Co., 1888. (Frankland)[8] | 4-47 |

An examination of our deep well water shows that it does not differ essentially from the results obtained at other points. Furthermore it shows but little fluctuation. The well has been examined at various times since it has been in operation and during the process of boring. The results of a bacteriological examination during the progress of the work and before the water was regularly pumped are

1. Proc. Ia. Acad. Sci. l. c.
2. Rep. Mass. State Brd, Health. 26:436.
3. Micro-Organisms of Water, 107.
4. Die Wasserversorgung von Zurich. 1885.
5. Rep. Wis. State Brd. Health. 17:107.
6. Proc. Ia. Acad. Sci. l. c.
7. Rep. Mass. Sta. Brd. Health. 26:440.
8. Micro-Organisms of Water, 106.

here given. Mr. Damon by a simple apparatus succeeded in making a qualitative analysis at different depths.

| Depth | No. of Bacteria per cc. First Determination | Second Determination |
|---|---|---|
| 0 | 26080 | |
| 3 | 500 | |
| 10 | 300 | 1870 |
| 15 | 430 | |
| 20 | 1160 | 255 |
| 25 | 2246 | |
| 40 | 650 | |
| 75 | 470 | 440 |
| 100 | 600 | 500 |
| 150 | 350 | 260 |
| 400 | 650 | 650 |
| 500 | 300 | 250 |
| 600 | 650 | 780 |
| 1500 | 1250 | |

The large number at 1500 feet was due to sediment and dirt which collected at this point where the men had to work a long time repairing the machinery which broke during the operation. The well was left open before the time of regular pumping, dust and dirt had accumulated, and hence the large number of bacteria present, at all points.

The water obtained from Iowa rivers has received only casual study. Mr. Steelsmith in the writer's laboratory found the following in the Iowa river at Marshalltown. During the examination there was an epidemic of typhoid fever. A large majority of liquefying species

| Source. | No. of Bacteria per cc |
|---|---|
| Water above mill dam June 7 (Steelsmith) | 2170 |
| Pumping Station June 7 (Steelsmith) | 1200 |
| Hydrant Dr. Mieghle's office (Steelsmith) | 1800 |
| Avg. from six hydrants September 9 (Steelsmith) | 2040 |
| Avg. from sixteen hydrants October 17 | 1900 |

were found. We also detected B. coli-communis. This undoubtedly came from the sewage which entered the river above Marshalltown water works.

The writer has also reported on the bacterial contents of Miss-

issippi river water at LaCrosse[0] Wis. To these we may add also a few other determinations made at Ames.

| | No. of Bacteria per cc |
|---|---|
| Hydrant, Fourth street, LaCrosse, Wis. | 4000 |
| Direct from Miss. river..........Z | 3000 |
| Squaw Creek* Ames, October 3 (Waterhouse) | 1000 |
| Squaw Creek, Ames, August 3 (Blanche) | 650 |
| Squaw Creek, Ames, September 6 (Blanche) | 840 |

*Among the germs isolated from Squaw Creek was one pathogenic to mice.

The number o: germs found in river waters at other points is indicated in the following table:

| | No. of Bacteria per cc |
|---|---|
| River Main above Wurzburg (Rosenberg)[1] | 520 |
| Riven Ure above York (Frankland)[2] | 33400 |
| River Ure above Ripou (Frankland) | 1800 |
| River Limant, Switz., Zurich Stadmulle (Schlatter)[3] Jan. to Feb. | 200-1900 |
| River Spree, Berlin Water Works, Apr. to Mch. (ProsKaner)[4] (May) 750; (Apr) | 17000 |
| River Seine at Ivry (Miquel)[5] (Aug.) 6780; (Dec.) | 78950 |
| River Thames at Hampton (Frankland)[6] 1888, (July) 1070; (Jan.) | 92000 |
| River Merrimac ,Mass., (Clark)[7] 1896 | 8700-10900 |
| River Merrimac, Mass., (Clark)[8] 1897. Avg. for Apr. 3768; (Sept.) | 14445 |
| River Potmac very turbid (Smith)[9] 1886 | 10000 |
| River Potomac very clear | 150 |
| River Mohawk below Mill Creek (Brown)[10] March 8, 1892 | 16388 |
| River Mohawk, Rome Water Works (Brown), March 3 | 42 |
| River Hudson, Troy, west side (Brown)[11] flood tide Jan. | 1950 |
| River Hudson, Troy, west side (Brown), ebb tide, February 5 | 904 |

### Stagnant Pools.

While many farmers have provided their live stock with a good pure water from deep tubular wells, some still depend upon the stagnant water which collects in artificial basins. In these there is a real element of danger to live stock. Not only do such basins contain refuse from barns, but other refuse from yards, and frequently from

0. Proc. Ia. Acad. Sci. Pt. 4. 1:94.
1. Archiv. of Hyglene, 1886:448.
2. Micro-Organisms of Water, 100.
3. Zeitsch. of Hygiene, 9:56
4. Zeitsch. of Hygiene, 2:401.
5. Man prat. d'Anaylse bact des Eaux, 132.
6. Micro-Organisms of Water, 90.
7. Rep. Mass. State Brd. of Health, 28:507.
8. Rep. Mass. Sta. Brd.
9. Popular Health Mag., 1:252.
10. Rep. N. Y. Sta. Brd. Health, 13:684.
11. Rep. N. Y. Sta. Brd. Health, 13:688.

poorly constructed privies. Dr. Stalker[12] has called attention to disease in live stock originating from contamination of water supply. While I have not been permitted to make many examinations, the results of three bacteriological analyses made in our laboratory are here given:

| Source. | No. of Bacteria per cc |
|---|---|
| Stagnant pond, Sept. 19 (Waterhouse) | 500 |
| Stagnant pond, Sept. 19 (Waterhouse) | 1162 |
| Stagnant pond, Sept. 19 (Waterhouse) | 2500 |

### Sewage Disposal.

Sewage contains an extraordinarly large number of bacteria. Dr. Sedgwick[1] states that the average of 126 bacterial analyses of Lawrence sewage made between November, 1888, and November, 1889, show 708000 per cc. The extremes were 102400 on February 27, 1889, and 3963000 on April 16. The numbers were comparatively high in April, May and June, and comparatively low from December to April. In the old College sewer the number of bacteria found in sewage was as follows: June 14, sewage water contained 6886 (Elmina Wilson). On September 25, it was found to contain 6120 bacteria per cc. Gas producing bacteria as well as Sarcina aurantiaca were abundant.

Dr. Frankland[2] in his report on the number of bacteria found in Dee sewage states that from 23,500 to 26,000,000 germs were found in the effluent of the Ballater sewage pond. Prausnitz[3] found 227,369 germs in the Isar river near the entrance of the principal sewer. According to Frank[4] the Landweber canal, which receives the sewage of Berlin and thence empties into the river Spree contained as much as 1,392,000 germs in June.

Various methods of sewage disposal are used. (1) Self purification, which is fairly effective only where large bodies of water occur. This purification is due not only to sedimentation and dilution, but to important biological changes going on between plants and animals. (2.) Chemical precipitation. By this process it is attempted to carry away certain insoluble precipitates which under favorable conditions may carry away some of the dissolved matter. (3.) Irrigation purposes. Geo. E. Waring[5] was a great advocate of this system. This has been discussed by Rafter[6]. One important phase of the question comes under intermittent sand filtration. (4.) Intermittent fil-

12. Some Observations on Contaminated Water Supply for Live Stock. Bull. Ia. Agrl. Exp. Sta., 13:118.

1. Exp. Invent. Mass. State Brd. Health. Pt. 2. 1889-1890:819.
2. Micro-Organisms in Water, 101.
3. Der Einfluss d. Munchener Canalisation auf die Isar, 1889. Munchen.
4. Zeitschr. f. Hygiene, 2:401.
5. The proper disposal of sewage. Separate from Yale Med. Jour., 1896.
6. Water Supply and Irrigation Papers. Bull. U. S. Geol. Surv., 22.

tration. This system has been tried sufficiently long in this country and in Europe to commend it to sanitarians as a most important way of purifying sewage. Rafter and Baker[1] state that the first mention of intermittent downward filtration was made by the Rivers Pollution Commission in 1870.

Many experiments have been made on the purification of sewage by sand filtration, but chiefly by the State Board of Health of Massachusetts[2] In these classical experiments an enormous amount of work has been recorded. From their experiments it was found that a very efficient filter bed could be constructed with a mixture of coarse and fine sand and fine gravel, 3 feet, 8 inches in depth. Through such a filter bed only 5 per cent of the bacteria were found in the effluent. In a later report[3] there is a full account of the practical workings of the Lawrence city filter which has done most efficient work. The Bacillus coli-communis, the characteristic organism of sewage, was found only a few times in the effluent. The subject of bacterial purification of sewage is not only a chemical process, but a biological one, and as Percy Frankland says[4], "In short, we have in these bacteria beds a very beautiful piece of biological machinery, which, however, like all delicate appliances, requires careful management, and is subservient to the law of the conservation of energy." It used to be held by certain German investigators that these ordinary sand filters had the power of arresting all bacteria. According to Piefke and others it was held that efficient filtration was brought about by the formation of a slimy mass about the particles. This slimy mass consists of bacteria which are the real filters. It is certainly true that in our own results the sand and gravel filters became more efficient with age. The sand and gravel was less compact at first, and I am inclined to think the filter was less efficient on this account. Fuller[5] regards the theory of Piefke, Flugge and Proskaner, who hold that the sticky coat ing of the surface lawers of filters is indispensable to satisfactorily remove the bacteria, as fallacious. He points out that the surface layer removes more bacteria in proportion to the thickness than any other layer. We have also noticed that when the surface of the filter is scraped it does not diminish the efficiency of the filter in the removal of bacteria.

In order to compare the efficiency of our filter plant with that of

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1. Rafter and Baker Sewage Disposal in the U. S., 228.
2. Exp. Invest. Mass. Sta. Brd. Health. Upon purification of sewage. Pt. 1, 2, 1889-1890.
   Rep. Mass. Brd. Health, 24, 26, 28, 29.
3. L. C., 24, 29:494.
4. Jour, Sanitary Inst., 20:395.
5. Rep. Mass. Sta. Bd. Hlth., 26:620.

the Massachusetts filter I insert here the results obtained by Mr. Clark[1] in their filter No. 6, which corresponds to our own.

| Averages for Months. | 1897 | 1898 |
|---|---|---|
| January | 49000 | 7100 |
| February | 20200 | 8300 |
| March | 27500 | 5800 |
| April | 11800 | 3700 |
| May | 6200 | 2150 |
| June | 3300 | 9050 |
| July | 1600 | 669 |
| August | 1200 | 235 |
| September | 900 | 484 |
| October | 1100 | 410 |
| November | 10900 | 623 |
| December | 6500 | 3144 |
| Average for twelve months | 11700 | 3472 |

This filter received at the rate of 60,500 gallons per acre for six days in the week in 1897, and 65,600 in 1898. In 1897 the Massachusetts results were worse and in 1898 a little better than at Ames in 1899, but the applied sewage was considerably weaker in 1898, and even in 1897 was weaker than the College sewage in 1899.

The filter beds of the College plant cover 0.4 acre. They consist of two beds, each 55 feet by 150 feet, made of mixed coarse and fine gravel and sand averaging 4 feet deep. For a detailed description see the paper by Professor Marston. The "effective size" is from 0.33mm. to 0.38mm., and the "uniformity coefficient" ranges from 7.1 to 11.6. The sewage is applied at the average rate of about 100,000 gallons per acre per day, for about 8½ months of the year, and about one-fourth this rate during the remaining time. The plant was put in operation September 15, 1898.

Bacteriological analyses were made daily of the effluent, and once a week samples were collected of the fresh sewage from the manhole, and of the sewage from the tank as it flows on the beds. No attempt has been made to determine the species except incidentally. In the effluent B. coli-communis and B. cloaceae were found during the early operation of the effluent. The B. coli-communis has repeatedly been found in the manhole and tank. We also found Sarcina vertriculi and S. aurantiaca in the manhole.

The detail of collecting and determining the number of bacteria was in charge of Senior students, Messrs. O. J. Fay, J. H. Grisdale, H. S. Hopkins, Dr. A. G. Hopkins, Dr. S. P. Smith, L. Russell Walker, and C. W. Warburton, to whom the writer desires to express his obligations.* For this work plain agar-agar was mostly used. The sam-

1. Rep. Mass. Sta. Bd. Hlth., 30:483; 29:438.

*I wish also to thank Dr. Kennedy of the State Board of Health, who gave me access to the library of the

ples were all collected in sterilized test tubes and a known quantity of the samples was taken out with a sterilized pipette and placed in melted agar-agar, and poured in Petri dishes. In the early work parallel peptone gelatin plates were poured, but as these did not differ essentially from the peptone agar-agar, the latter was used exclusivly. The filter bed has been under observation for more than a year. During the first two or three weeks of the operation of the filter bed the bacteria were not removed very efficiently. From September 15 to October 1 the effluent had 656,200 to 1,250,800. The manhole on October 1 had 750,000; tank, 372,000; the effluent, 656,000. Evidently biological filtration had not been operating sufficiently to remove the sewage bacteria and the filter bed was not compact enough. The effluent gradually contained a smaller number of bacteria. On November 5 there were 12,200 bacteria per cc. On December 1 the manhole contained 3,160,000, the tank 940,000, effluent 22,680 bacteria per cc. From December 26 to January 2, the effluent did not run. On January 11 the manhole had 345,864, tank 31,200, effluent 8,600 bacteria per cc. The filter bed was frozen on February 9 and the effluent was not obtained until April 30, when it contained 4,075 bacteria per cc. May 3 the manhole had 194,956, tank 168,600, effluent 11,520. During the month of May the number of batceria in the effluent fluctuated between 1,770 and 18,000. The efficiency of the west filter bed which was sampled much more frequently than the east is shown from the fact that the tank on June 28 contained 1,108,000 bacteria per cc., the effluent only 2,640. The effluent worked very satisfactorily during the month of July. The lowest number found in the effluent of the west bed was 960 on July 2. The sewage discharge was then less, owing to the College vacation. The efficiency of the east filter bed is also shown in the removal of bacteria. The manhole on July 5 had 708,000 bacteria, the tank 814,000, effluent 1,280. On August 9 the number of bacteria in manhole ran up to 3,840,000, tank 1,240,000, effluent 3,000. September 5 an unsual number of bacteria were found in the manhole. This high number kept up during the entire month of September. On September 5, 9,000,000; September 12, 8,600,000; September 19, 7,260,000; September 27, 9,600,000; on the 5th the effluent of the west filter bed had only 600 bacteria. The effluent o the east filter bed on September 27 had 8,160. On October 3, the number of bacteria in manhole dropped to 4,800,000, with a few less in the tank. The effluent from the west filter bed contained 3,720 per cc. There was no appreciable change in the manhole till October 24, when the number increased to 6,760,000. The effluent from west filter bed had 3,820 bacteria per cc. There was a continuous rise till November 7, when the number dropped to 6,800,000, the tank contained 4,350,000, the effluent of west filter bed contained 2,040. The explanation of the rise and fall of the

bacteria in the manhole and tank is not far to seek. Temperature is the important factor. This is shown in the following table:

## Temperature Records of Manhole, Tank, Air and Filter Bed in Degrees F.

| Date, 1899 | | Manhole | Tank | Air | Soil Temperatures West Filter Bed North End | | |
|---|---|---|---|---|---|---|---|
| Day | Hour | | | | 12 in. Deep | 24 in Deep | 36 in. Deep |
| Apr. 29 | 1 30 p m | 59 | 63 | 63.5 | 59.5 | 60 | 57 |
| May 3 | " | 57 | 61 | 72 | 60 | 57.5 | 55.5 |
| " 13 | 1 15 p m | 56.5 | 58 | 60 | 56.25 | 59.5 | 62.75 |
| " 24 | 2 00 p m | 55 | 56 | 74 | 58 | 56 | 57.25 |
| June 3 | 1 30 p m | 58 | 60 | 80 | 67 | 67.5 | 67 |
| " 16 | 1 00 p m | 63 | 63 | 94 | 63 | 64 | 66.5 |
| " 24 | " | 59 | 61 | 79 (5 20 pm) | 69 (5 20 pm) | 70 (5 20 pm) | (74 5 20 pm) |
| July 5 | 1 30 p m | 61.5 | 63 | 85 | 65 | 66.5 | 68 |
| " 21 | " | 64 | 67 | 107 | 78 | 76.5 | 75 |
| Aug. 10 | 5 00 p m | 69 | 70 | 92 | 68.5 | 68.5 | 73 |
| " 17 | 11 15 a m | 68 | 67 | 87 | 68 | 69 | 69.5 |
| " 24 | 5 30 p m | 66 | 64 | 66 | 74 | 74 | 74 |
| " 29 | 9 10 a m | 72 | 71 | 82 | 72 | 73 | 73.5 |
| Sept. 5 | 8 45 a m | 78 | 77.5 | 89 | 75 | 75.5 | 75 |
| " 12 | 2 45 p m | 75.5 | 77 | 83 | 68.5 | 69.5 | 70.5 |
| " 19 | 10 45 a m | 68 | 68 | 72 | 64 | 64 | 64 |
| " 27 | 2 50 p m | 78 | 77 | 83 | 60 | 61.5 | 62 |
| Oct. 3 | 2 20 p m | 71 | 70 | 73 | 60.5 | 60.5 | 62 |
| " 10 | 2 30 p m | 56.5 | 56 | 54.5 | 60.5 | 60.5 | 59.5 |
| " 17 | 8 40 a m | 47 | 48 | 48 | 56 | 60 | 61 |
| " 24 | 10 10 a m | 76 | 75 | 82 | 64.5 | 64.5 | 63.5 |
| " 31 | 2 30 p m | 72 | 71 | 73 | 53 | 53.5 | 53 |
| Nov. 7 | 2 20 p m | 54 | 55 | 56 | 52 | 50 | 47 |
| " 14 | 2 10 p m | 47 | 49 | 46 | 49 | 50 | 50 |
| " 21 | 10 10 a m | 56 | 56 | 54 | 51 | 50 | 48.5 |
| Dec. 18 | 1 30 p m | 53 | 48 | 31.5 | — | 35.5 | 38.5 |

There is very little difference in the number of bacteria per cc. in manhole and tank. The greater number of organisms in the manhole is no doubt due to the solid particles contained therein which are largely removed before it enters the tank. On the other hand the tank contains a large amount of more food for bacteria and as some time

elapses before the tank is discharged we can readily see that there would be a large number of bacteria.

The monthly averages of bacteria in effluent of filter bed is shown in the following table:

| Month, 1899. | Number of Bacteria per cc |
|---|---|
| January, 15 days | 9867 |
| February, 3 days | 3450 |
| March, 0 days | |
| April, 1 day | 11075 |
| May, 27 days | 8965 |
| June, 27 days | 4539 |
| July, 31 days | 2538 |
| August, 31 days | 2736 |
| September, 30 days | 3693 |
| October, 29 days | 4203 |
| November, 26 days | 2925 |
| December, 27 days | 2335 |
| Average for Eleven Months | 5127 |

This is a remarkably good showing, considering that owing to inundations in June by heavy rains and the frozen condition of the beds from February to May, part of the results are abnormally high. These results should be compared with those of the Massachusetts Filter No. 6, given on another page.